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(71) Applicants (<i>for all designated States except US</i>): KOREA ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY [KR/KR]; 373-1 Kusong-dong, Yusong-gu, Taejon 305-701 (KR). DONAM SYSTEMS INC. [KR/KR]; 373-1 Kusong-dong, Yusong-gu, Taejon 305-701 (KR).			
(72) Inventors; and			
(75) Inventors/Applicants (<i>for US only</i>): KIM, Byoung, Yoon [KR/KR]; C-2 Daedong Village, Kung-dong, Yusong-gu, Taejon 305-335 (KR). YUN, Seok, Hyun [KR/KR]; 135-1201 Hanbit Apt., Uheun-dong 99, Yusong-gu, Taejon 305-333 (KR). KIM, Hyo, Sang [KR/KR]; Department of Physics, KAIST, 373-1 Kusong-dong, Yusong-gu, Taejon 305-701 (KR).			
(74) Agent: HUH, Jin, Seok; 206 Sungji Building, 1338-22 Seocho-dong, Seocho-ku, Seoul 137-070 (KR).			
(54) Title: OPTICAL AMPLIFIER WITH ACTIVELY CONTROLLED SPECTRAL GAIN AND FIBER LIGHT SOURCE WITH DESIRED OUTPUT SPECTRUM			
(57) Abstract			
<p>This invention relates to an optical amplifier capable of adjusting the gain curve to a desired shape. This invention also relates to a fiber light source capable of producing desired output spectrum. The method to use passive wavelength filters for the gain flattening of erbium doped fiber optical amplifier is well known. However, the disadvantage with this method is that the gain curve varies depending on input optical signal power, gain level or changes in surrounding temperature. However, the optical amplifier of the present invention provides desired shapes of gain curves at various gain levels in spite of the reconfiguration of optical communication networks or the changes in driving conditions since the amplifier includes an active wavelength tunable filter and a gain detection system. The fiber light source of the present invention operates without external input light, producing spectrum-sliced output light from amplified spontaneous emission.</p>			

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OPTICAL AMPLIFIER WITH ACTIVELY CONTROLLED SPECTRAL GAIN AND FIBER LIGHT SOURCE WITH DESIRED OUTPUT SPECTRUM

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TECHNICAL FIELD

The present invention relates to an optical amplifier, more specifically to an optical amplifier capable of adjusting the gain curve by actively controlling the spectral gain of the optical amplifier.

10 The present invention also relates to a light source, more specifically to a fiber light source capable of obtaining spectrum-sliced output light for the use of WDM(Wavelength Division Multiplexed) optical communication systems.

BACKGROUND ART

15 Gain-flattening of optical amplifiers has been a hot topic of research since it is directly related to the transmission capacity of WDM optical communication systems. In the prior art, passive wavelength filters with fixed loss curves have been used for the gain-flattening of optical amplifiers.

20 FIG. 1 shows a schematic of a dual-stage EDFA(Erbium Doped Fiber Amplifier) employing a passive gain-flattening filter according to the prior art. Referring to FIG. 1, a passive gain-flattening wavelength filter 100 is inserted between the first EDF(Erbium Doped Fiber) 110 and the second EDF 111. Fiber gratings or thin-film filters are generally used as 25 passive gain-flattening filter 100. The length, doping concentration or the like of the respective EDFs as well as the pumping direction or power of the pumping lights 120 and 121 may differ depending on the situations. In

FIG. 1, optical signals 130 and 131 enter the EDFA bidirectionally, but occasionally optical signals may unidirectionally enter the EDFA. In this EDFA, optical signals are amplified in the first and second EDFs 110 and 111 after passing through WDM couplers 140 and 141. The dual-stage 5 EDFA shown in FIG. 1 provides superior gain and noise characteristics to a single-stage EDFA in spite of the optical loss resulting from wavelength filter 100. When the optical signal is unidirectionally input to the dual-stage EDFA, an additional optical isolator may be provided beside wavelength filter 100 to suppress backward spontaneous emission.

10 The gain variation of a conventional EDFA is more than a few dB in the wavelength region of interest, typically over 30 nm around 1550 nm. FIG. 2 schematically shows the gain profiles across the 1500 - 1600nm region of the spectrum before and after the gain flattening using an appropriate wavelength filter. Gain-flattening is very important for the 15 WDM optical communication systems. However, when the operating conditions of the optical amplifier such as input signal power, gain, pumping power, temperature and the like are changed, flat gain profile can not be obtained since the gain characteristics of the EDF varies. Such changes in the operating conditions may arise from the reconfiguration or 20 degradation of the optical communication networks. Therefore, to realize stable and flexible WDM optical communication systems, intelligent optical amplifiers are needed which can actively cope with various changes in operating conditions.

25 The optical amplifier utilizing Raman nonlinear effect in an optical fiber has widely been studied along with the EDFA. The basic configuration of the Raman optical amplifier is similar to that of the EDFA shown in FIG. 1 but it employs a telecommunication grade fiber, a special

fiber with a numerical aperture("NA") giving high Raman efficiency or a phosphosilicate based fiber with large Raman wavelength shift. The Raman optical amplifier is pumped by a high power laser having more than a few hundred mW pump power and a wavelength that is determined by the 5 specific Raman wavelength shift of the fiber used. The wavelength range of the Raman gain curve is about 100nm wider than that of a common EDF but the gain variation is too large for the use of the WDM optical communication systems. Therefore, even in the case of the Raman optical amplifier, intelligent optical amplifiers are needed which can actively cope 10 with various changes in operating conditions to achieve gain-flattening.

DISCLOSURE OF THE INVENTION

It is therefore an object of the present invention to provide an 15 optical amplifier that can actively obtain the desired gain profile through the dynamic filter response to the various changes in operating conditions.

It is other object of the present invention to provide a fiber light source that can obtain the desired spectral line shape through the dynamic filter response to the various changes in operating conditions.

In order to achieve the object, the optical amplifier according to the 20 present invention comprises a length of optical waveguide having a gain medium therein, optical pumping means, optical input means and at least one wavelength tunable filter.

In the embodiment of the optical amplifier, the gain medium may 25 be composed of the different types of gain optical fibers. The wavelength tunable filter is disposed between two different types of gain optical fibers. Preferably, the wavelength tunable filter comprises filter driving means for controlling the loss profile of the tunable filter. Feedback signals calculated

from the measured gain curve of the optical amplifier is applied to the filter driving means in order to actively adjust the gain curve. The optical amplifier may further comprise temperature detecting means to compensate temperature change in the inside of the optical amplifier. Preferably, the 5 wavelength tunable filter is an all-fiber acousto-optic wavelength filter based on coupling between spatial modes in optical fibers.

In order to achieve the other object, the fiber light source according to the present invention comprises a length of gain optical fiber, optical pump means for generating spontaneous emission by inducing population 10 inversion in the gain optical fiber, at least one wavelength tunable filter and filter driving means. Preferably, the wavelength tunable filter is an all-fiber acousto-optic wavelength filter based on coupling between spatial modes in optical fibers.

In the embodiment of the fiber light source, a Fabry-Perot filter is 15 used to obtain a wavelength sliced output spectrum.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a schematic of a dual-stage EDFA employing a passive gain flattening filter according to the prior art;

20 FIG. 2 is a graph schematically showing gain profiles of a conventional EDFA before and after the gain flattening using an appropriate wavelength filter;

FIG. 3 shows the configuration of the optical fiber acousto-optic 25 wavelength tunable filter commonly used in the optical amplifier and the fiber light source according to the present invention;

FIG. 4 shows the configuration of the unidirectional dual-stage optical amplifier;

FIGS. 5A and 5B show gain curves before and after the gain flattening for different powers of saturating signal of -13dBm and -7dBm, respectively;

5 FIGS. 6A and 6B show the loss curves of the wavelength tunable filter for two different saturation powers of -13dBm and -7dBm, respectively;

FIG. 7A is a graph showing flattened gain curves at various operating gain levels of the optical amplifier according to the present invention, which is obtained by adjusting the filter;

10 FIG. 7B is a graph showing gain tilt produced when the filter is not adjusted;

FIG. 8 shows the configuration of the optical amplifier according to a second embodiment of the present invention;

15 FIG. 9 shows the configuration of the active and intelligent optical amplifier according to a third embodiment of the present invention;

FIG. 10 shows the configuration of a fiber light source according to the other aspect of the present invention; and

20 FIG. 11 is a graph showing a representative spectrum of the spectrum-sliced optical output generated from the fiber light source of the invention.

BEST MODE FOR CARRYING OUT THE INVENTION

The present invention will now be described in detail referring to the accompanying drawings. However, the embodiments hereinafter 25 described should be interpreted as illustrative and in no sense limiting.

Referring to FIG. 3, the wavelength tunable filter for the gain-flattening is composed of two devices AOTF1 and AOTF2 connected in

series. Acoustic wave generators are composed of piezoelectric devices 200 and 201 and acoustic horns 203 and 204. The Acoustic wave generators are driven by the alternating electrical signals from filter drivers 210 and 211. The generated acoustic wave propagates along single mode optical fibers 5 220 and 221. When the wavelength of the acoustic wave coincides with the beat length between modes, mode-coupling is induced.

The first device AOTF1 employs a telecommunication grade single mode fiber($NA = 0.11$, core diameter= $9.2 \mu\text{m}$, cladding diameter= $125 \mu\text{m}$). The acoustic wave propagates along the length of 15cm in the single mode fiber. Mode-coupling to the respective cladding modes(LP12, LP13, LP14) 10 was achieved by applying three electrical signals generated from singal generators rf1, rf2 and rf3 to piezoelectric device 200. The half width half maximum of this filter was 3.3, 4.1 and 4.9nm, respectively.

The second device AOTF2 employs a single mode fiber with the 15 cut-off wavelength of about $1 \mu\text{m}$ ($NA = 0.12$, core diameter= $7.0 \mu\text{m}$, cladding diameter= $100 \mu\text{m}$). The fiber length for inducing mode-coupling was 5cm. Mode-coupling to the respective cladding modes(LP11, LP12, LP13) was achieved by applying three electrical signals generated from singal generators rf4, rf5 and rf6 to piezoelectric device 201. The half 20 width half maximum of this filter was 8.0, 8.6 and 14.5nm, respectively.

The maximum response speed mainly depends on the length of the optical fiber. In the case of two devices AOTF1 and AOTF2, they were 95 μs and 25 μs , respectively. The first device AOTF1 with narrow linewidth was used in flattening the gain over the 1530nm range, whereas the second 25 device AOTF2 with broad linewidth was used in flattening the gain over the 1555nm range. The basic optical loss of two devices due to the connection of optical fibers was less than 0.5dB.

FIG. 4 shows the configuration of the unidirectional dual-stage optical amplifier employing gain-flattening wavelength tunable filter 300 and signal generator 310 described in FIG. 3. Optical fibers 320 and 321 doped with erbium of about 300ppm concentration exhibit about 2.5dB/m absorption at 1530nm, respectively. The first stage optical fiber 320(length: 10m) was pumped with 980nm laser diode 330 to enhance the noise characteristics. When -10dBm optical signal was pumped with 20mW power at 1550nm, more than 10dB gain as well as more than 4dB noise figure were achieved. The second stage optical fiber 321(length: 24m) was pumped with 1480nm laser diode 331. Furthermore, an optical isolator 340 was used to suppress the backward spontaneous emission and the effect of reflected signals. The two optical fibers have different physical property since at least one parameter of the optical fibers such as core radius, material, doping concentration or length is different from each other. Instead of erbium doped optical fibers 320 and 321, optical fibers obtaining optical gain from Raman nonlinear effect or semiconductor optical amplifying media may be used.

A 1547.4nm DFB(Distributed FeedBack) laser output and LED(Light Emitting Diode) output were input to the above optical amplifier as a saturating signal and a probe light, respectively. Then, the gain and noise figure were measured by detecting the respective intensities of amplified LED light and spontaneous emission using a wavelength analyzer. In the first embodiment, the input probe light power was -27dBm over the range 1520nm to 1570nm, which was adjusted to be higher than that of spontaneous emission by more than 3dB as well as much lower than that(-13 ~ -7dBm) of the DFB light for the reduction of measurement error.

FIG. 5A shows the gain curves before and after the gain flattening

when the saturating signal(DFB light) power is -13dBm. The gain curve 400 before the gain flattening was obtained when electrical signals are not applied to the filter. On the other hand, the gain curve 402 after the gain flattening was obtained by adjusting the loss curve of the filter to minimize 5 the gain variation. Referring to FIG. 5A, the gain after the gain flattening approaches a constant value(22dB) over the 35nm range between 1528nm and 1563nm. The arrow 410 represents the wavelength of the saturating signal.

FIG. 5B shows the gain curves 420 and 422 before and after the 10 gain flattening when the saturating signal power is -7dBm. 16dB flat gain was obtained by adjusting the loss curve of the filter.

FIGS. 6A and 6B show the loss curves of the wavelength tunable filter for two different saturation powers of -13dBm and -7dBm, respectively. The wavelength tunable filter is the one used for the optical 15 amplifier according to the first embodiment of the present invention. The loss curves 452 and 454 produced by the first and second devices AOTF1, AOTF2 of FIG. 3 were combined to form a total loss curve 450 in log scale. Likewise, the total curve 460 was formed from the loss curves 462 and 464. As described above, the first and second devices AOTF1 and AOTF2 were 20 used in flattening the gain over the 1530nm and 1555nm ranges, respectively. The six arrows indicate the center wavelengths of the notches produced by six alternating electrical signals. In the case of FIG. 6A, the frequency and voltage of applied electrical signals were 2.0076MHz; 10.04V, 2.4015MHz; 9.96V, 2.9942MHz; 23.2V, 1.0277MHz; 15V, 25 1.5453MHz; 9V and 2.3357MHz; 17.2V, when measured with the output impedance of 50 Ω . In the case of FIG. 6B, they were 2.0078MHz; 4.74V, 2.3989MHz; 7.58V, 2.9938MHz; 14.02V, 1.0348MHz; 20.02V,

1.5391MHz; 13.2V and 2.3375MHz; 15.8V. If the efficiency of the acoustic wave generator is enhanced and an optical fiber having smaller diameter is employed, the drive voltage can be lowered less than 1V.

The active optical amplifier according to the first embodiment of the present invention can be used to obtain a desired gain curve under various operating conditions unlike the conventional passive optical amplifier. The advantage of the active optical amplifier could be validated through the following experiment. In the experiment, the loss curve of the filter as well as the pumping power for the second stage optical fiber were adjusted to obtain 19dBm flat gain when the saturating signal power was -10dBm.

FIG. 7A shows flattened gain curves at various operating gain levels of the optical amplifier according to the present invention, which is obtained by adjusting the filter. On the contrary, FIG. 7B shows gain tilt produced when the filter is not adjusted.

Referring to FIG. 7A, the curve 500 is a flattened gain curve for the pumping power of 42mW. In general, pumping power and filter profile should be readjusted to change the gain of an optical amplifier. The curves 502 and 504 are flattened gain curves obtained when the pumping powers are changed to 75mW and 21mW and filter profiles are adjusted to reach the gain levels of 22.5dB and 16dB, respectively. The noise figures 510 are less than 5dB over the 35nm range between 1528nm and 1563nm.

The optical amplifier employing this filter with actively tunable loss curve can produce flattened gain profiles at various gain levels. However, the optical amplifier employing the conventional passive wavelength filter can no more produce flattened gain profiles for the adjustment of gain levels since it is designed to produce flattened gain profiles at a specific

gain level.

FIG. 7B shows the experimental result to demonstrate this problem. In the experiment, the filter was adjusted to obtain flattened 19dB gain at the pumping power of 42mW. Then, the pumping power was increased up 5 to 75mW without changing the loss curve of the filter. In this case, the gain 522 increased on the whole, but a gain variation of 3dB was observed over the 35nm range. When the pumping power was decreased to 21mW, the gain 524 decreased with a gain variation of about 4dB. Such gain tilts were expected to be a problem of the optical amplifier employing passive 10 wavelength filters, exhibiting the limitation of the conventional optical amplifier applications.

On the other hand, a gain detection system that can determine whether the measured gain curve coincides with a desired gain profile is required to realize a self-adjusting optical amplifier in spite of the changes 15 in operating conditions.

FIG. 8 shows the configuration of the optical amplifier according to a second embodiment of the present invention, which employs an optical gain detection system. The gain detection system can detect the gain of the optical amplifier by comparing the spectrum of input light to that of output 20 light. Referring to FIG. 8, the first and second stage amplifiers are composed of pumping lasers 604 and 606, WDM couplers, and erbium doped optical fibers 600 and 602. An active wavelength tunable filter 610 having a desired loss curve is disposed between optical fibers 600 and 602. Along with active wavelength tunable filter 610, a passive wavelength filter 25 having a specific loss curve may be used for a variety of purposes.

The operation of the gain detection system is as follows.

Some part of incoming multi-wavelength optical signals 620 are

input to a wavelength filter 640 such as a rotatable diffraction grating and a Fabry-Perot filter by a fiber coupler 630. The fiber coupler 630 has a low wavelength dependence as well as low coupling ratios of less than a few percents. Then, an optical detector 650 measures the optical signal intensity
5 as a function of wavelength while the wavelength filter 640 is tuned.

The optical signals amplified at the first and second stage amplifiers are transmitted through a fiber coupler 631 and a wavelength filter 641 to an optical detector 651 for the detection of signal intensities as a function of wavelength. The fiber coupler 631 also has a low wavelength
10 dependence as well as low coupling ratios of about a few percents. The gain curve is obtained by comparing the measured input and output signal intensities. From the comparison of the gain curve with a desired gain curve, a controller 660 calculates the required pumping power and filter profiles. The respective pumping lasers 604, 606 and filter driver 670 are
15 controlled according to the calculation results. Through such a feedback of the controller 660, an active and intelligent optical amplifier, capable of obtaining a desired gain curve in spite of changes in external conditions, with a response time less than 1ms can be realized.

FIG. 9 shows the configuration of the active and intelligent optical
20 amplifier according to a third embodiment of the present invention, which employs an optical gain detection system different from the optical gain detection system described in FIG. 8. This configuration is basically similar to that of FIG. 8, however, there is a difference in obtaining the gain curve of the optical amplifier. Referring to FIG. 9, the spectrum of the backward
25 spontaneous emission is obtained after transmitting an optical coupler 680 at the input port and a wavelength filter 640 to an optical detector 650. The gain curve of the optical amplifier can be obtained from the spectrum and a

well-known amplifier modelling formula. Then, a controller 660 calculates the required pumping power and filter profiles from the comparison of the gain curve with a desired gain curve. The respective pumping lasers 604, 606 and filter driver 670 are controlled according to the calculation results,
5 as was described in FIG. 8.

Further, the gain detection system of FIG. 8 or FIG. 9 may include a thermometer capable of detecting the temperature inside the optical amplifier. If the temperature change is compensated in spite of the temperature dependence of the gain curve of the erbium doped optical fiber
10 or the wavelength tunable filter, the total gain curve of the optical amplifier can have a desired shape.

FIG. 10 shows the configuration of a fiber light source according to the other aspect of the present invention. The configuration of the fiber light source is similar to those of the above-described optical fibers.
15 However, the difference is that the fiber light source can actively produce optical output spectra using the amplified spontaneous emission generated from a pumped gain optical fiber without external input optical signals. In the case of employing an erbium doped optical fiber, an output spectrum can be obtained with a broadband of more than 30nm at 1550nm center
20 wavelength. Referring to FIG. 10, the gain optical fiber is divided into two parts, similar to the above-described dual-stage optical amplifier. The first stage optical fiber 700 and the second stage optical fiber 701 are pumped contra-directionally by optical pumping means 710 and 711 to increase the optical power. The one end 720 of the first stage optical fiber 700 is cut at angles to reduce reflectance, and the other end of the first stage optical fiber 700 connected to the one end of the second stage optical fiber 701 through a wavelength tunable filter 730. The other end of the second stage
25

optical fiber 701 is connected to an optical isolator 740 to avoid the optical feedback from the outside. Along with wavelength tunable filter 730, a mid-stage optical isolator 741 is installed to remove the backward amplified spontaneous emission travelling from the first stage to the second 5 stage, enhancing the power of the forward optical output 750. If necessary, an additional fixed wavelength filter 760 can be installed to obtain a variety of output spectra. For example, if a Fabry-Perot filter having a free spectral range of 0.8nm or 1.6nm and a finesse of more than 10 is used as fixed wavelength filter 760, spectrum-sliced output light, adequate for the light 10 source of WDM optical communication systems, can be obtained. Moreover, the desired optical power for each wavelength channel of the spectrum-sliced output spectrum can be obtained by adjusting a filter driver 735. For example, if the optical loss or gain in interconnected communication systems is different for each channel, signal to noise 15 characteristics for each channel can be optimized by adjusting the optical power for each channel of the light source. That is, higher optical power is supplied for a channel of high optical loss and lower optical power for a channel of low optical loss, respectively.

FIG. 11 is a graph showing a representative spectrum of the 20 spectrum-sliced optical output generated from the fiber light source of the invention. Referring to FIG. 11, the optical power for each channel is flattened over a few tens of nanometer wavelength range.

The above-described active optical amplifier provides a variety of gain curves in various driving conditions of WDM optical communication 25 systems. For example, a constant gain level can be obtained in spite of changes in surrounding temperature, spectrum hole-burning effect resulted from the change in optical input power or the like. Also, the gain flatness

can be maintained even when the gain level is varied by the reconfiguration of the optical communication networks. In the case of an optical transmission line including a plurality of amplifiers, the active optical amplifiers may be used for all amplifiers. Otherwise, the active optical amplifier may be used between every a few passive optical amplifiers.

5 Moreover, it may be used as a front-stage amplifier between a light source and an optical transmission line when the optical transmission line shows wavelength dependent irregular optical loss or gain. In this case, signal to noise characteristics for each wavelength can be optimized by adjusting the optical power of the light, which is input to the optical transmission line, for each wavelength at the front-stage amplifier. That is, low power light is input to the optical transmission line for the wavelength showing great optical loss therein. On the contrary, high power light is input to the optical transmission line for the wavelength showing small optical loss therein.

10

15 The fiber light source according to the other aspect of the invention can produce desired output spectrum since it actively copes with the changes in external conditions. Therefore, it can be used in the applications of a fiber-optic gyroscope, a white-light interferometer or characteristics analysis on the devices used in WDM optical communication systems.

20 Moreover, the spectrum-sliced light source with a periodic transmittance can be used as a light source of WDM optical communication systems. In this case, the wavelength dependent optical loss in the optical transmission line is compensated by controlling the optical power of each wavelength channel to a desired state to yield optimal signal to noise ratio.

What is claimed is:

1. An optical amplifier for amplifying multi-wavelength optical signals according to a desired gain profile as a function of optical wavelength, comprising:

a length of an optical waveguide which has a gain medium therein;

pumping means coupled to said waveguide for pumping said gain medium;

input means for introducing the optical signals to said waveguide;

and

at least one wavelength tunable filter, each providing optical loss as a function of optical wavelength.

2. The optical amplifier of claim 1, wherein said gain medium is any one selected from the group consisting of an optical fiber doped with rare-earth ions, an optical fiber obtaining optical gain from Raman nonlinear effect and a semiconductor optical amplifying medium.

3. The optical amplifier of claim 1, wherein said gain medium is an erbium doped optical fiber providing optical gain in the range of 1530-1650nm and said pumping means is a semiconductor laser with a wavelength of 980 or 1480nm.

4. The optical amplifier of claim 1, wherein said gain medium is composed of at least two types of gain optical fibers whose at least one parameter selected from the group of core radius, material, doping concentration and length is different from each other.

5. The optical amplifier of claim 1, further comprising at least one passive wavelength filter having a fixed loss profile.

6. The optical amplifier of claim 1, further comprising filter driving means for applying electrical signals to each wavelength tunable filter in

order to control each loss profile of the tunable filter.

7. The optical amplifier of claim 6, further comprising:

gain monitoring means for measuring said gain profile; and

a controller that determines the loss profile necessary to obtain a desired gain profile and control the said filter driving means to generate and apply electrical signals to said tunable filter(s) until said measured gain profile becomes the same as said desired profile with an accuracy.

8. The optical amplifier of claim 7, wherein said gain detecting means measures the gain of optical signals at their wavelengths by comparing the signal intensities before and after the optical signals transmit the optical amplifier.

9. The optical amplifier of claim 7, wherein said gain detecting means is a device for obtaining gain profile by measuring the backward amplified spontaneous emission spectrum at, at least, one position of the optical amplifier.,.

10. The optical amplifier of claim 7, wherein said controller includes:

temperature detecting means for measuring the temperature inside the optical amplifier; and

a device for applying feedback signals to said filter driving means for the gain profile of the optical amplifier to have a desired shape by compensating the change in the gain profile of said gain medium as well as that in the loss profile of said wavelength tunable filter due to the temperature change.

11. The optical amplifier of claim 7, wherein the loss profile of the each wavelength tunable filter is controlled so that the gain profile maintain a constant value while the gain variation in the gain wavelength range is

minimized.

12. The optical amplifier of claim 1, wherein said wavelength tunable filter is an optical fiber acousto-optic wavelength filter.

13. The optical amplifier of claim 12, wherein said optical fiber acousto-optic wavelength filter is composed of at least two types of optical fibers whose at least one parameter selected from the group of core radius, cladding radius and refractive index distribution is different from each other, said optical fibers supporting at least one core mode and at least one cladding mode.

14. The optical amplifier of claim 6, wherein said wavelength tunable filter is an optical fiber acousto-optic wavelength filter, said filter driving means generating at least one alternating signal with its frequency and voltage being controlled actively.

15. The optical amplifier of claim 14, wherein the frequency of the electrical signal has a value in the 0.1-100MHz range and the wavelength of the acoustic wave generated in said wavelength tunable filter has a value in the 10/ μ m-10mm range.

16. The optical amplifier of claim 1, further comprising at least one optical isolator.

17. A fiber light source, comprising:
a length of gain optical fiber doped with a gain constituent;
optical pump means optically coupled to said gain optical fiber for generating spontaneous emission by inducing population inversion in the gain optical fiber;
at least one wavelength tunable filter placed at, at least, one position of said gain optical fiber, each having a loss profile as a function of optical wavelength;

filter driving means for applying electrical signals to each wavelength tunable filter in order to control each loss profile of the tunable filter;

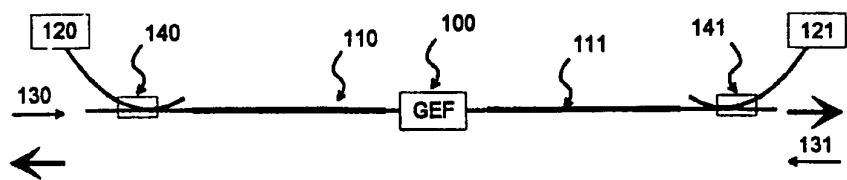
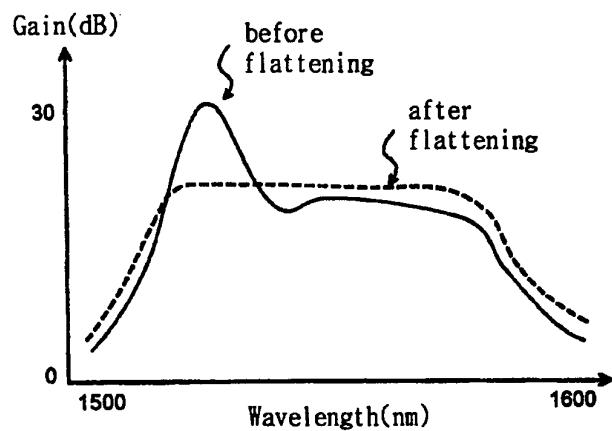
wherein the spectrum of the amplified spontaneous emission generated in said gain optical fiber has a desired shape at the output port of the fiber light source.

18. The fiber light source of claim 17, further comprising at least one fixed wavelength filter at, at least, one position of said gain optical fiber.

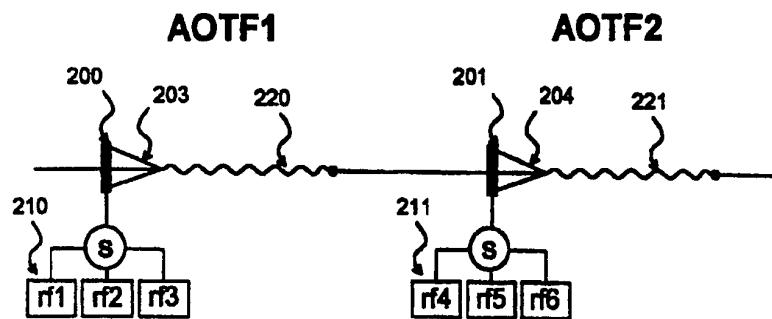
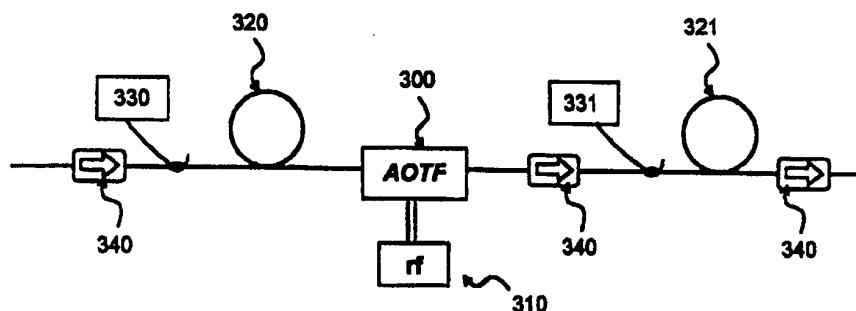
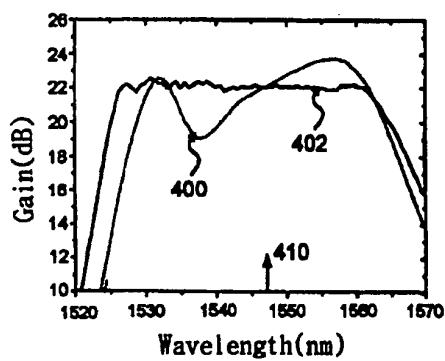
19. The fiber light source of claim 18, wherein said passive fixed wavelength filter is a Fabry-Perot filter, the free spectral range of said Fabry-Perot filter being narrower than the full width half maximum of the amplified spontaneous emission so that the output light may have an evenly spaced wavelength-sliced spectral shape.

20. The fiber light source of claim 19, wherein said free spectral range has any value selected from 0.4nm, 0.8nm or 1.6nm.

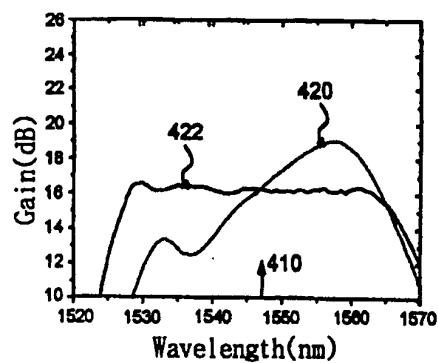
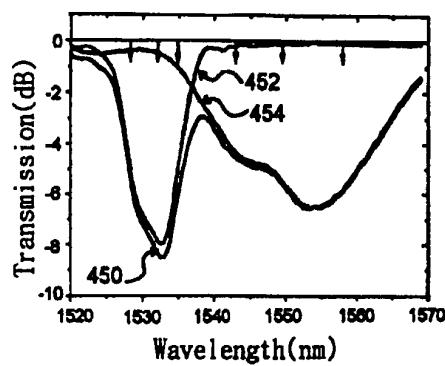
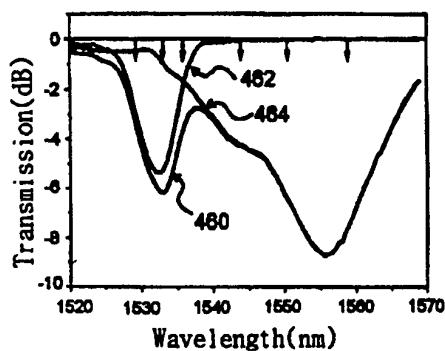
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FIG. 1**FIG. 2**

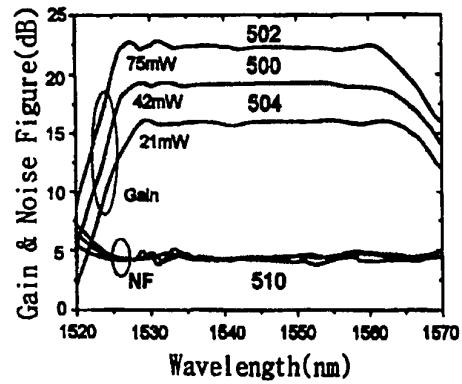
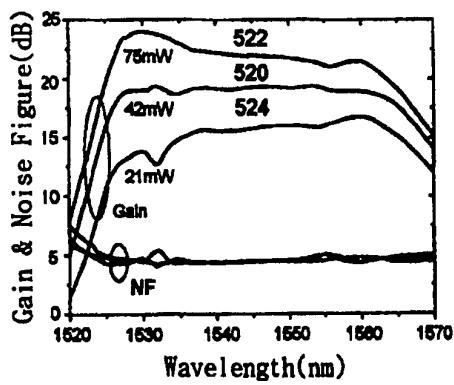
2/7

FIG. 3**FIG. 4****FIG. 5A**

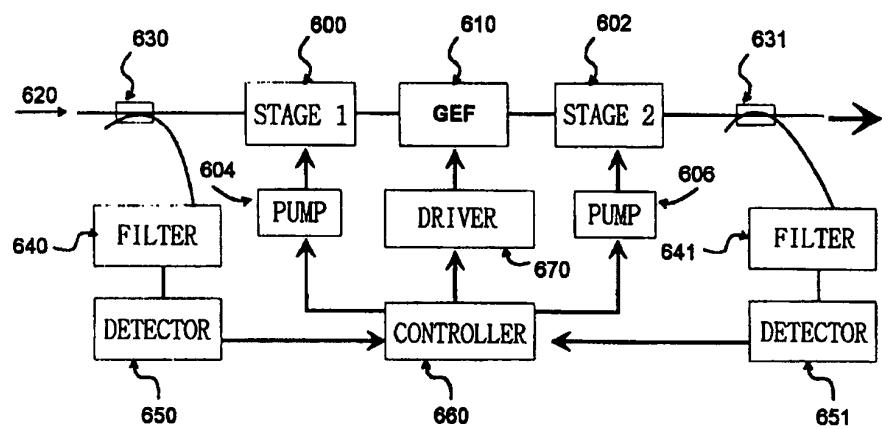
3/7

FIG. 5B**FIG. 6A****FIG. 6B**

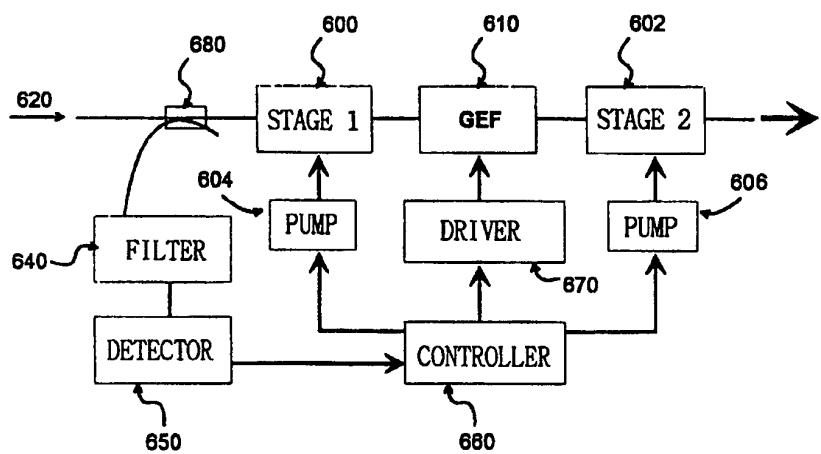
4/7

FIG. 7A**FIG. 7B**

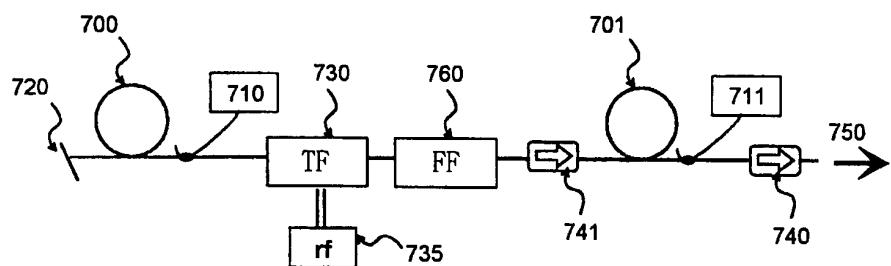
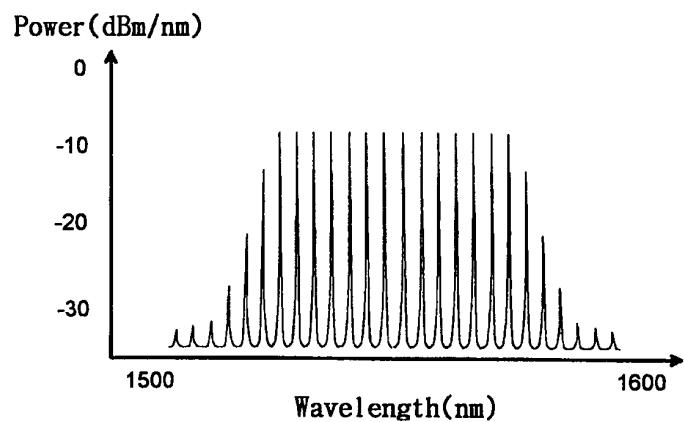
5/7

FIG. 8

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FIG. 9

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FIG. 10**FIG. 11**

INTERNATIONAL SEARCH REPORT

International application No. PCT/KR 98/00254
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A. CLASSIFICATION OF SUBJECT MATTER

IPC⁶: H 01 S 3/07, 3/10; G 02 F 1/39; H 04 B 10/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC⁶: H 01 S; G 02 F; H 04 B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 713 273 A2/3 (OKI ELECTRIC INDUSTRY COMPANY, LTD.) 22 May 1996 (22.05.96), claims; fig. 1,5-7,12.	1-20
A	US 5 392 377 A (AURACHER) 21 February 1995 (21.02.95), fig. 1-3; claims.	1-20
A	US 5 278 686 A (GRASSO et al.) 11 January 1994 (11.01.94), claims; abstract.	1-20
A	US 5 524 118 A (KIM et al.) 04 June 1996 (04.06.96), abstract.	1-20
A	US 5 457 568 A (JACOBOWITZ) 10 October 1995 (10.10.95), totality.	1-20

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See patent family annex.

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- ..&" document member of the same patent family

Date of the actual completion of the international search 14 May 1999 (14.05.99)	Date of mailing of the international search report 21 May 1999 (21.05.99)
Name and mailing address of the ISA/AT Austrian Patent Office Kohlmarkt 8-10; A-1014 Vienna Facsimile No. 1/53424/535	Authorized officer Heinrich Telephone No. 1/53424/454

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/KR 98/00254

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Document de brevet cité dans le rapport de recherche		Date de publication	Membre(s) de la famille de brevets	Date de publication
EP A2	713273	22-05-1996	CA AA EP A3 JP A2	2162975 713273 8213676
US A	5392377	21-02-1995	DE CO EP A1 EP B1 JP A2	59306835 590379 590379 8222412
US A	5278686	11-01-1994	CA AA DE CO DE T2 EP A1 EP B1 ES T3 IT AO MI IT A JP A2	2062665 69226719 69226719 506163 506163 2121812 910864 1247845 5130044
US A	5524116	04-06-1996	GB AO GB A1 GB B2 JP A2 JP B2	9425586 2295921 2295921 8162697 2695122
US A	5457568	10-10-1995	keine - none - rien	